

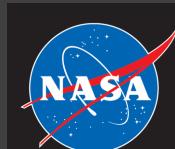
# Towards global constraints on short-wave radiative properties of ice clouds

Bastiaan van Diedenhoven

(Columbia University, NASA GISS)

Brian Cairns, Ann Fridlind and Andrew Ackerman  
(NASA GISS)

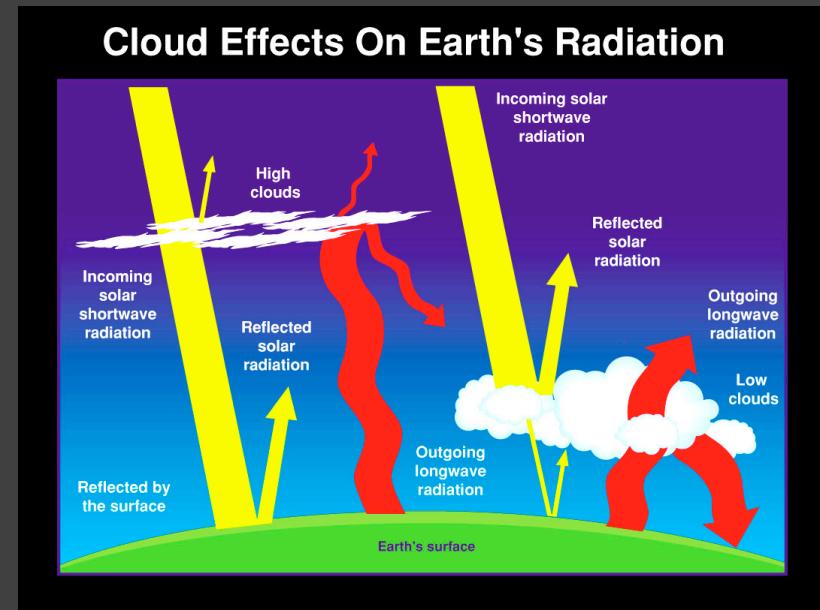
Thanks to Tim Garrett, Ping Yang, Igor Geogdzhayev, MAS team



National Aeronautics and Space Administration  
**Goddard Institute for Space Studies**  
New York, N.Y. 10025

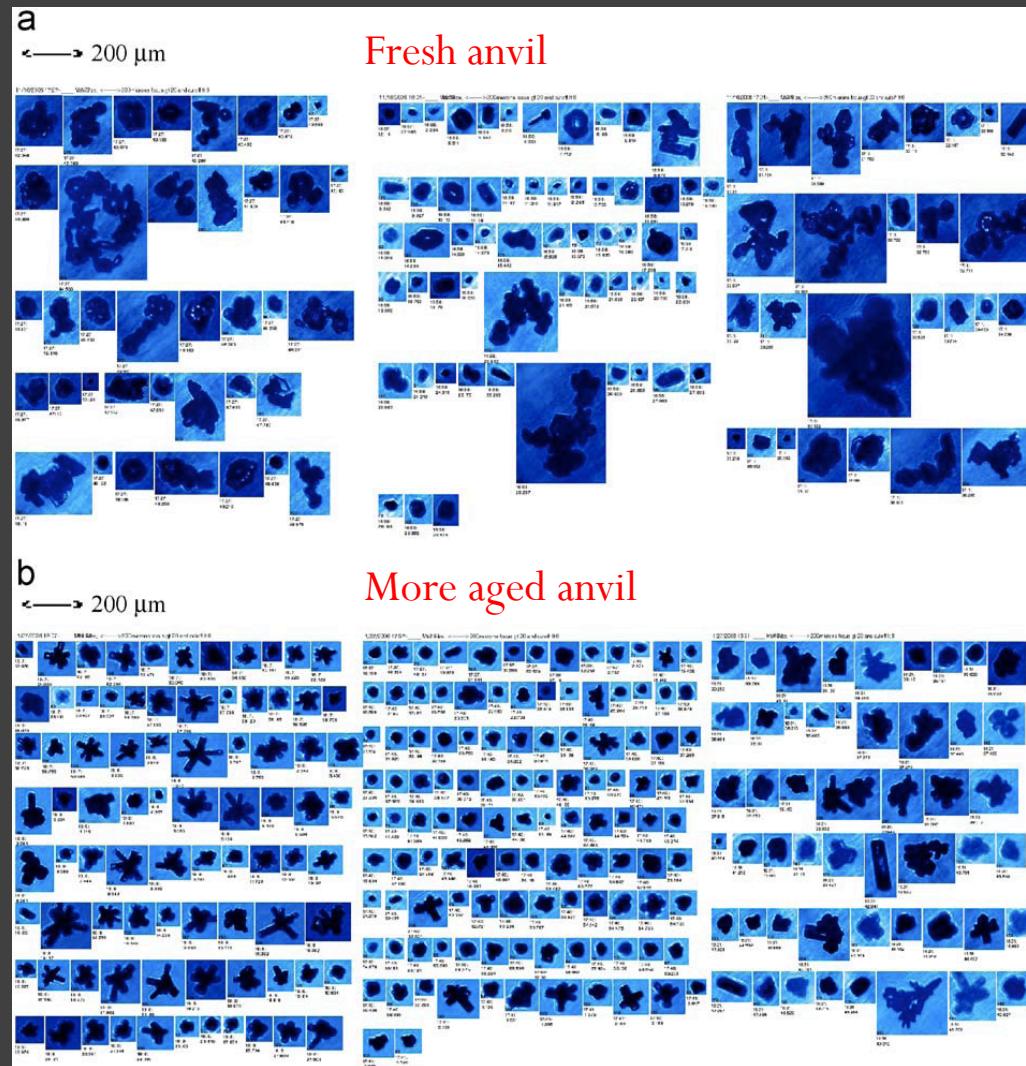
# Ice clouds in climate models

- Ice clouds can have large radiative effect
- Climate models need improve representation of ice cloud
  - Macrophysical properties
  - Microphysical properties
  - Optical properties



# Ice crystals in clouds

From Baran, JQSRT 2009



# Solar reflection by ice clouds (2-stream): Optical thickness

Cloud reflection is function of:

- Optical thickness  $\tau$
- Single scattering albedo  $\omega_0$  ( $R_{\text{eff}}$ )
- Asymmetry parameter  $g$

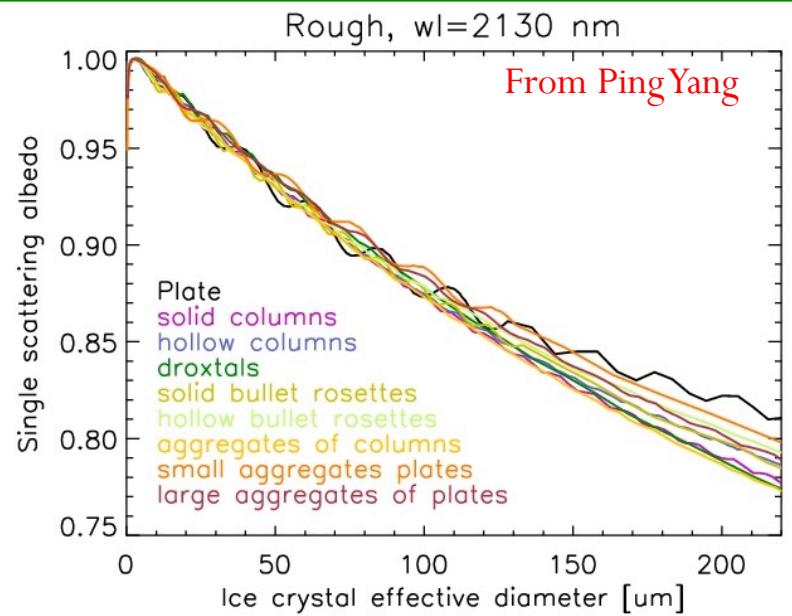
$$\tau = \int_0^\infty \int_0^\infty \sigma_e(D, Z) N(D, Z) dD dZ$$
$$\sigma_e \approx 2A_p \quad (A_p = \text{Projected area})$$

# Solar reflection by ice clouds: Effective radius

Cloud reflection is function of:

- Optical thickness  $\tau$
- Single scattering albedo  $\omega_0$  ( $R_{\text{eff}}$ )
- Asymmetry parameter  $g$

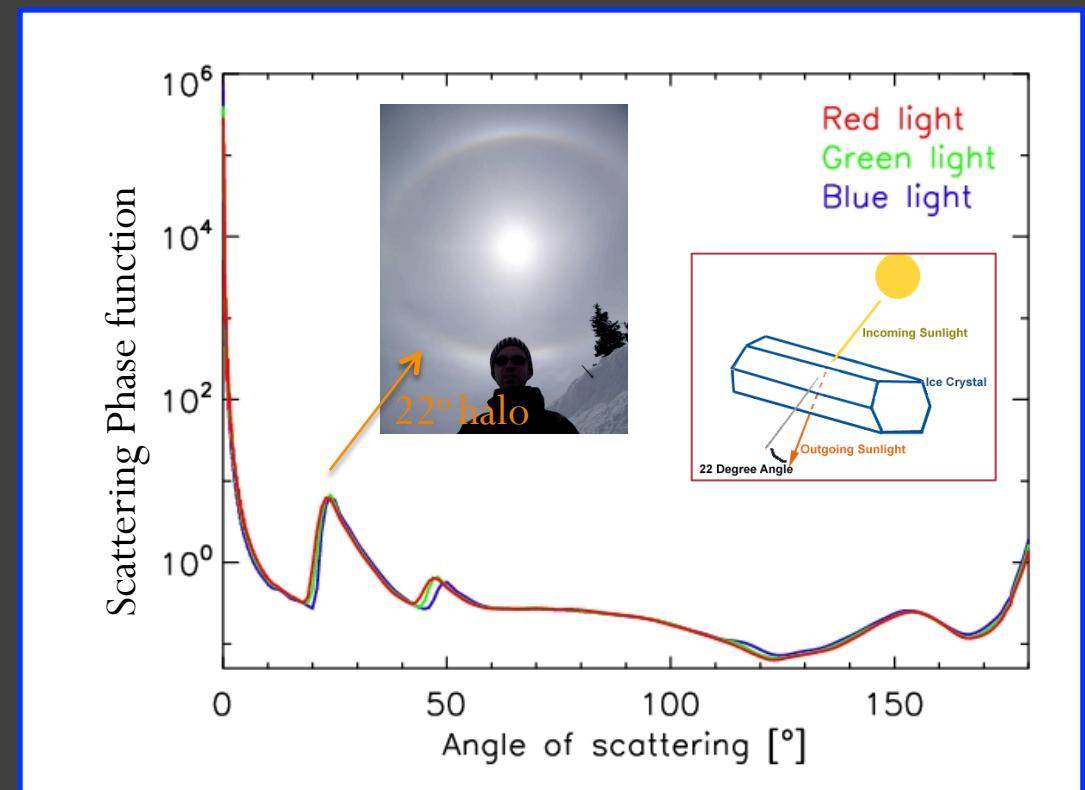
$$R_{\text{eff}} = \frac{3}{4} \frac{\int_0^\infty V(D)N(D) dD}{\int_0^\infty A_p(D)N(D) dD} ,$$



# Ice crystal asymmetry parameter

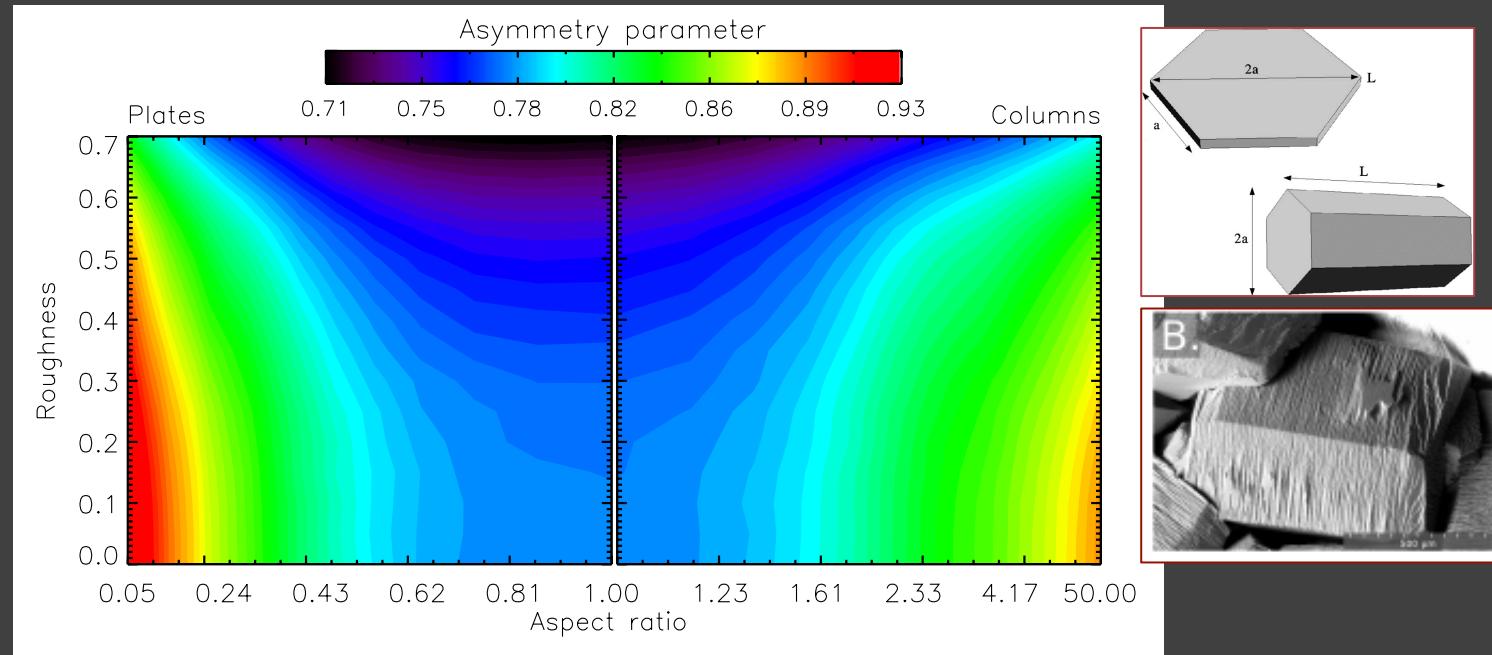
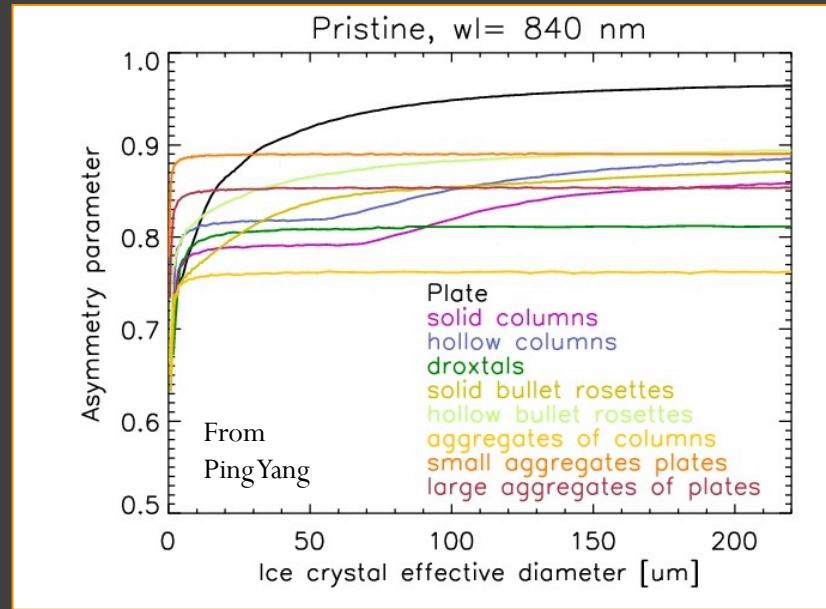
- $g=1$ : forward scattering
- $g=0$ : isotropic scattering
- Ice crystals:  $g \sim 0.6-0.95$

$$g = \int_0^{\pi} P_{tot}(\theta) \cos(\theta) \sin(\theta) d\theta$$



# Ice crystal asymmetry parameter

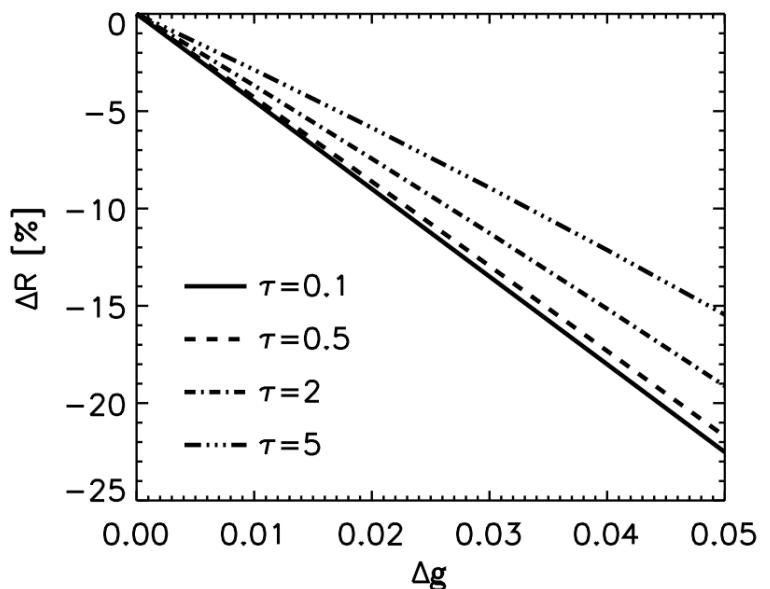
- Ice crystal g depends on
  - Shape
  - Microscopical Roughness/ impurity



# Solar reflection by ice clouds: Ice crystal asymmetry parameter

- Ice crystals:  $g \sim 0.6-0.95$
- Example:
  - Solar flux =  $342 \text{ W/m}^2$ ,
  - $R_{\text{cloud}} = 0.3$
  - 10% error in  $R_{\text{cloud}}$   $\sim 10 \text{ W/m}^2$
- Vogelmann & Ackerman, 1995:  
To constrain global flux error to 5%  
accuracy  $g$  required:
  - 2-5% (0.01-0.04)

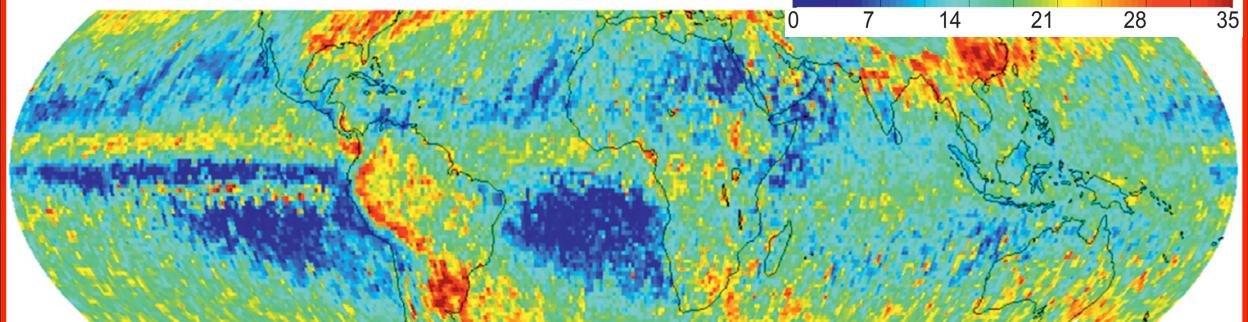
Cloud reflection error caused by error in  $g$ :



# Global ice cloud properties

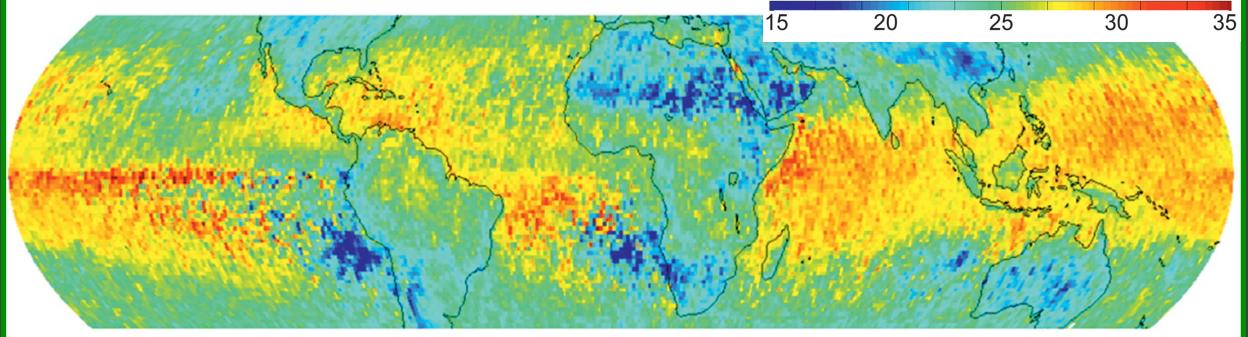
- Visible + Near-infrared reflectances:
  - Optical thickness
  - $R_{\text{eff}}$
- Nakajima-King method
- Global asymmetry parameter unconstrained

e) Cloud Optical Thickness Ice



Maddux et al.,  
JAOT 2010

c) Cloud Effective Radius Ice ( $\mu\text{m}$ )



**Ice cloud asymmetry parameter:**

Models: 0.6-0.95

In situ:  $\sim 0.75$

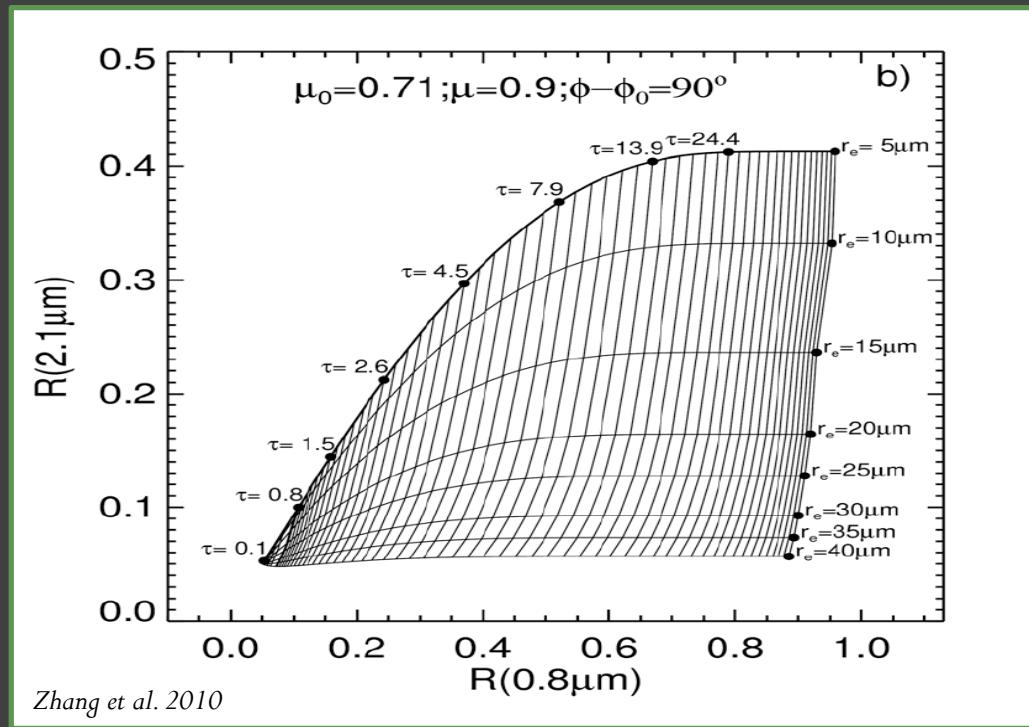
Required accuracy: 0.01-0.04 (Vogelmann & Ackerman, 1995)

?

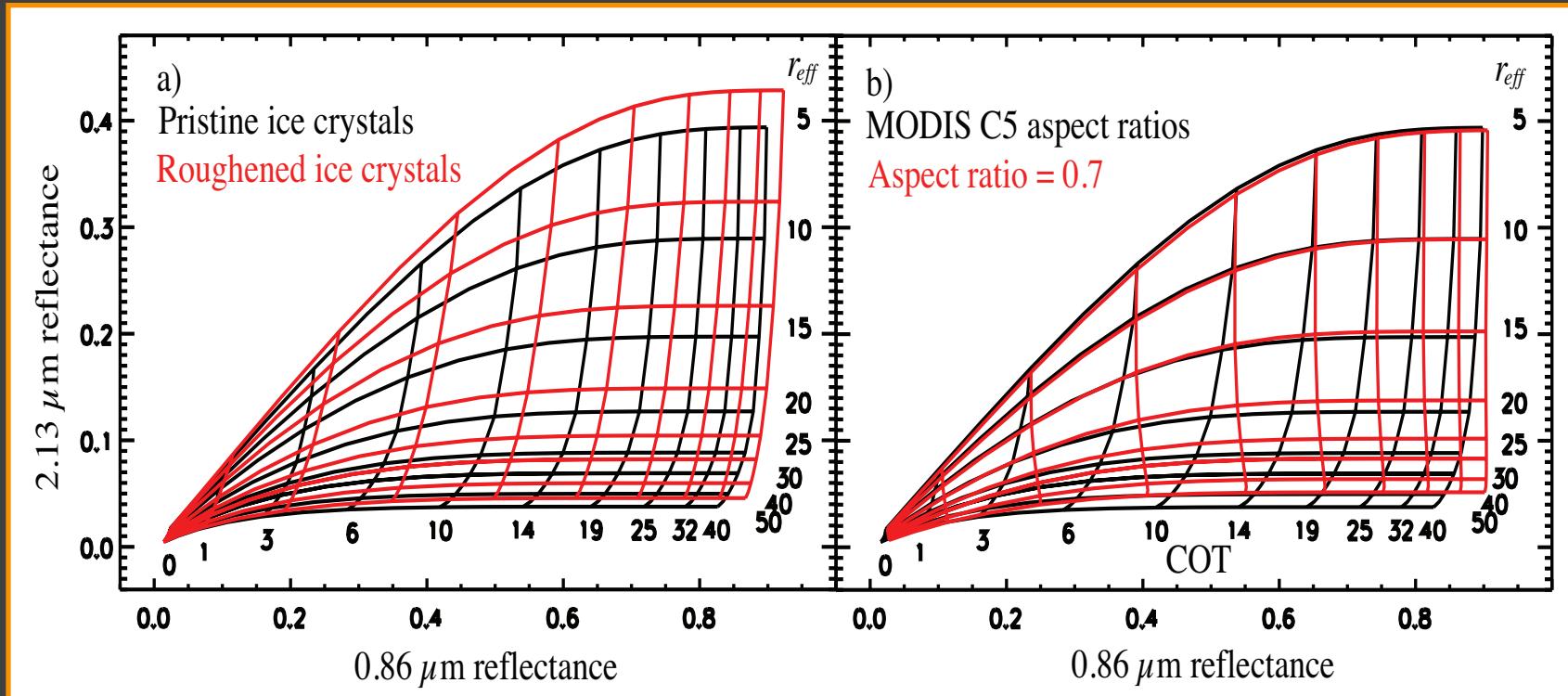
?

# Retrieval of effective radius and cloud optical thickness

- Cloud optical thickness
  - Ice crystal effective radius
- from 0.87  $\mu\text{m}$  (non-absorbing)  
and 2.13  $\mu\text{m}$  (absorbing)



# Nakjima-King depends on asymmetry parameter

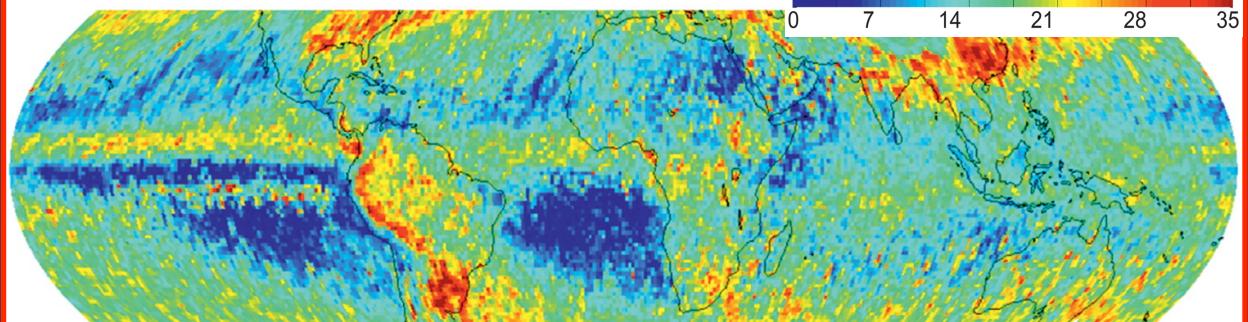


- Assuming lower  $g$  leads to
  - Larger  $R_{\text{eff}}$
  - Lower optical thickness

# Global ice cloud properties

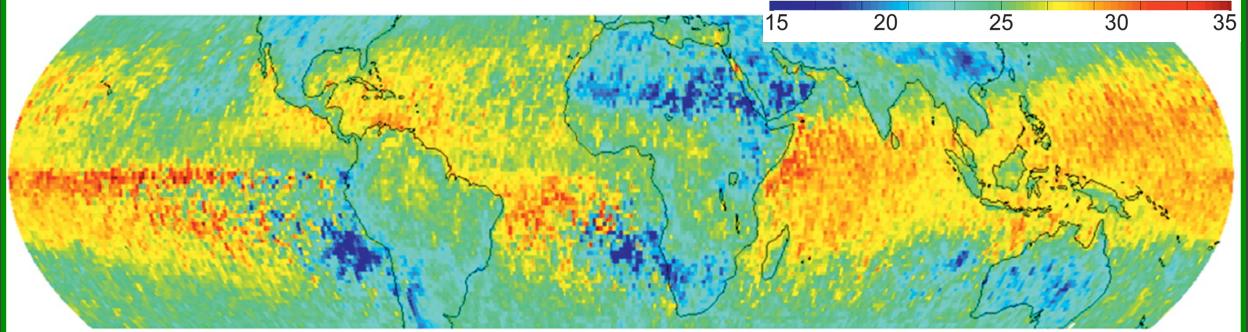
- Visible + Near-infrared reflectances:
  - Optical thickness
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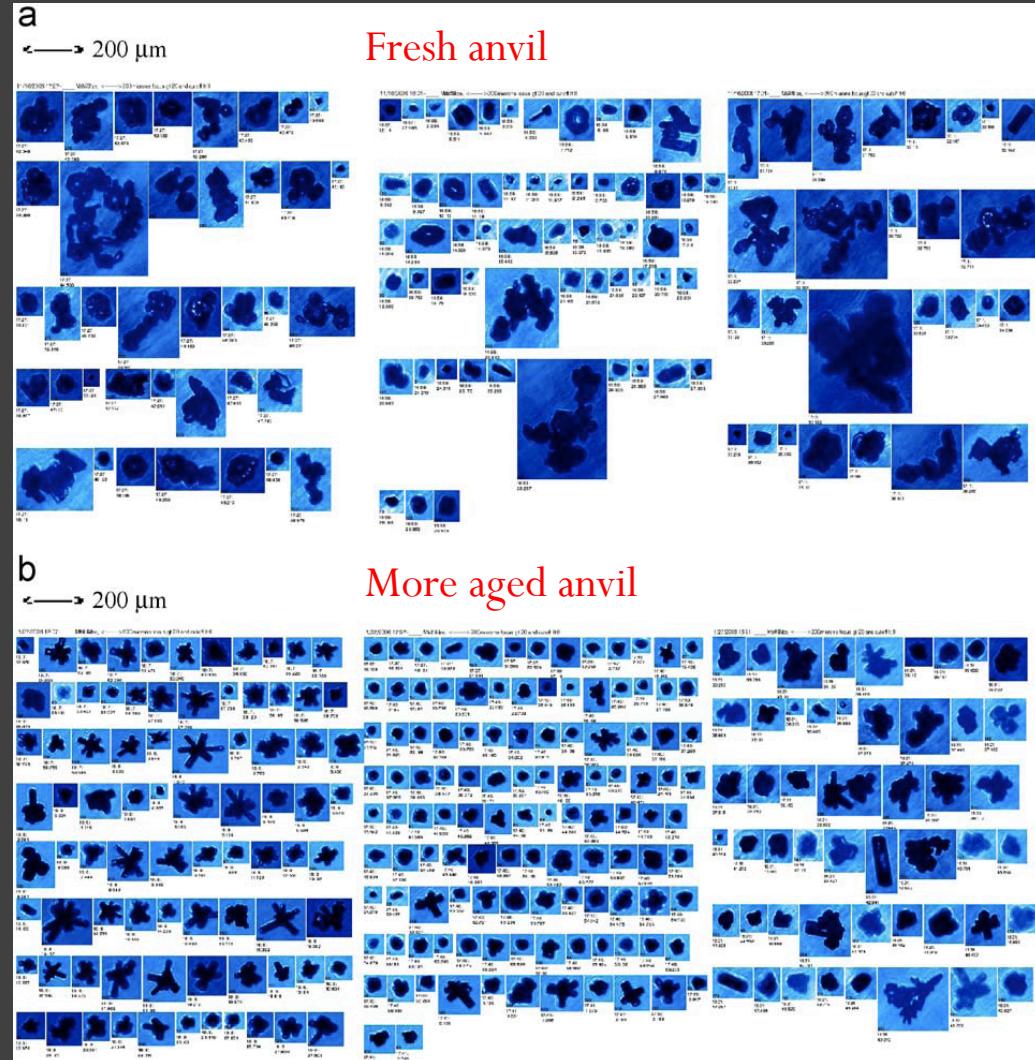
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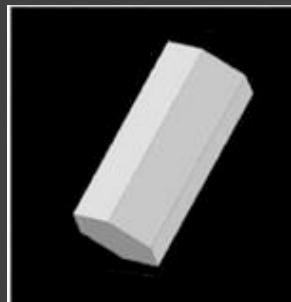
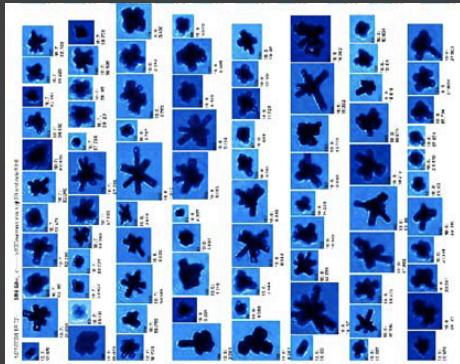
# Ice crystals in clouds

From Baran, JQSRT 2009

- Cloud Particle Imager:
  - Many irregular shapes
  - Many small ‘quasi-spherical’ crystals
  - Some more ‘pristine’ rosettes in aged anvil and cirrus

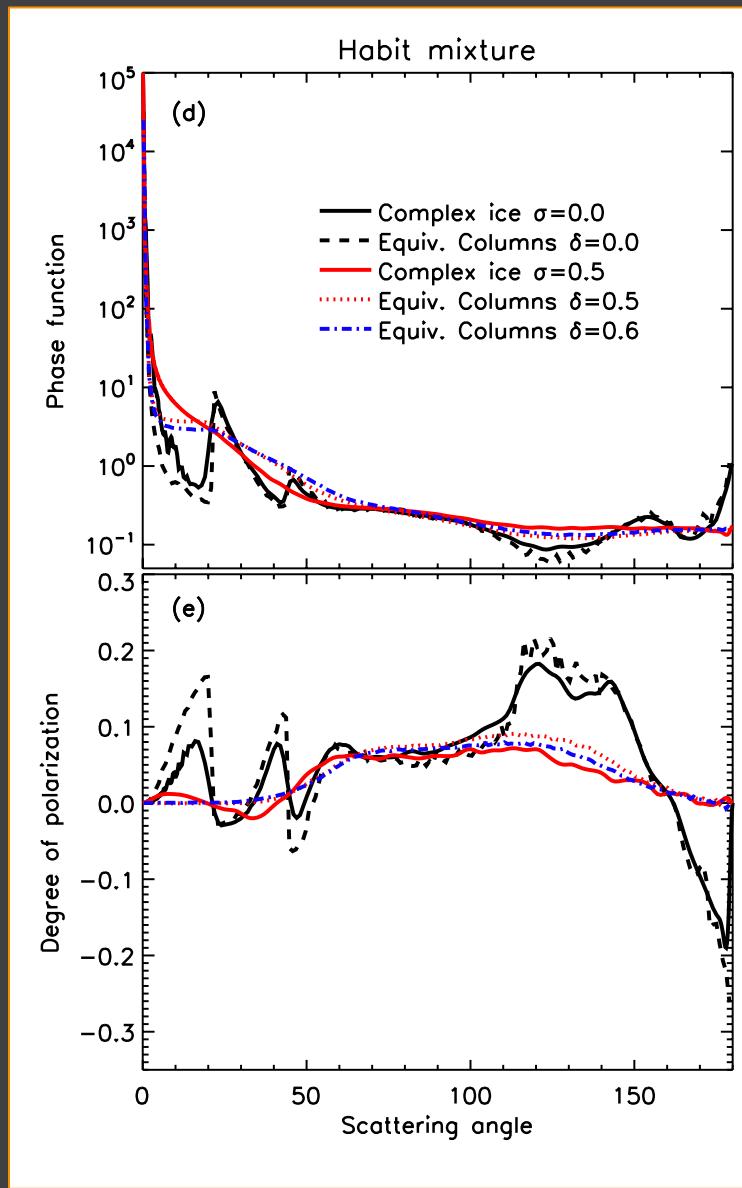


# Complex vs simple ice crystals

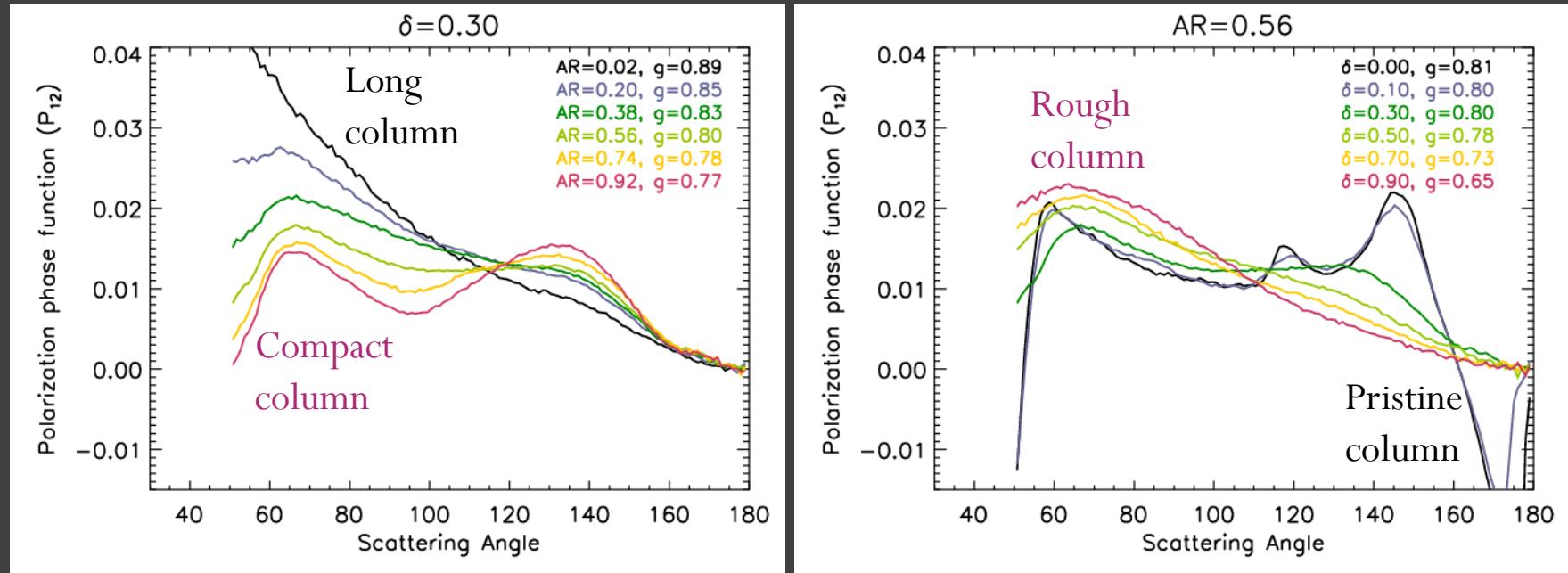


- Simulated scattering phase matrix
  - Solid lines: complex mixture
    - 34% Bullet rosettes
    - 33% Aggregate of columns
    - 33% Columns
  - Broken lines: equivalent columns
    - Same mean aspect ratio and roughness
- Columns/Plates can be used as surrogates for complex ice

(Fu 2007; Um & McFarquhar 2007; 2009)



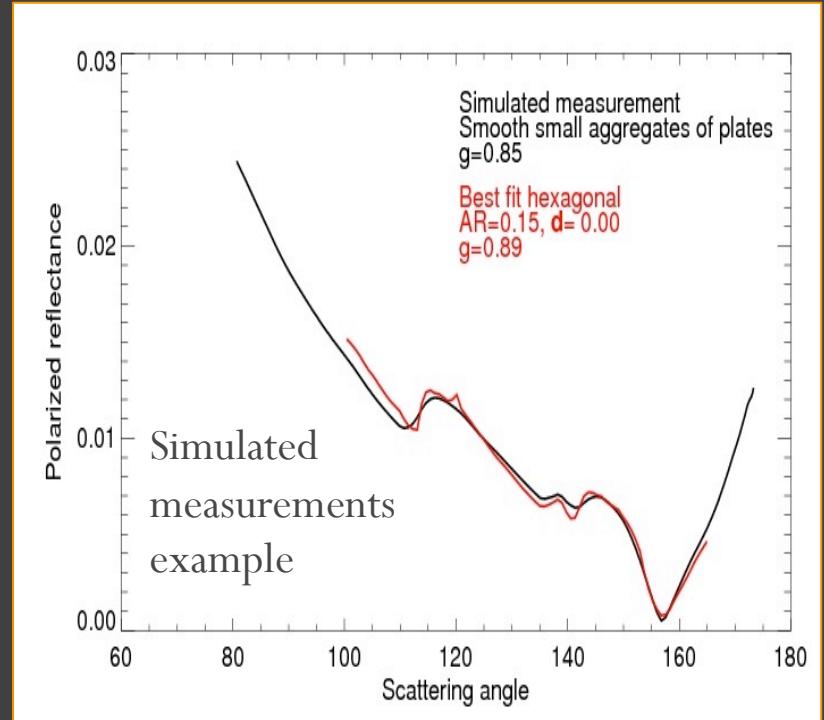
# Polarization dependence on aspect ratio and roughness



- $P_{12}$  contains info about aspect ratio and roughness
- Multi-directional polarized reflectance measurements largely conserve  $P_{12}$  features

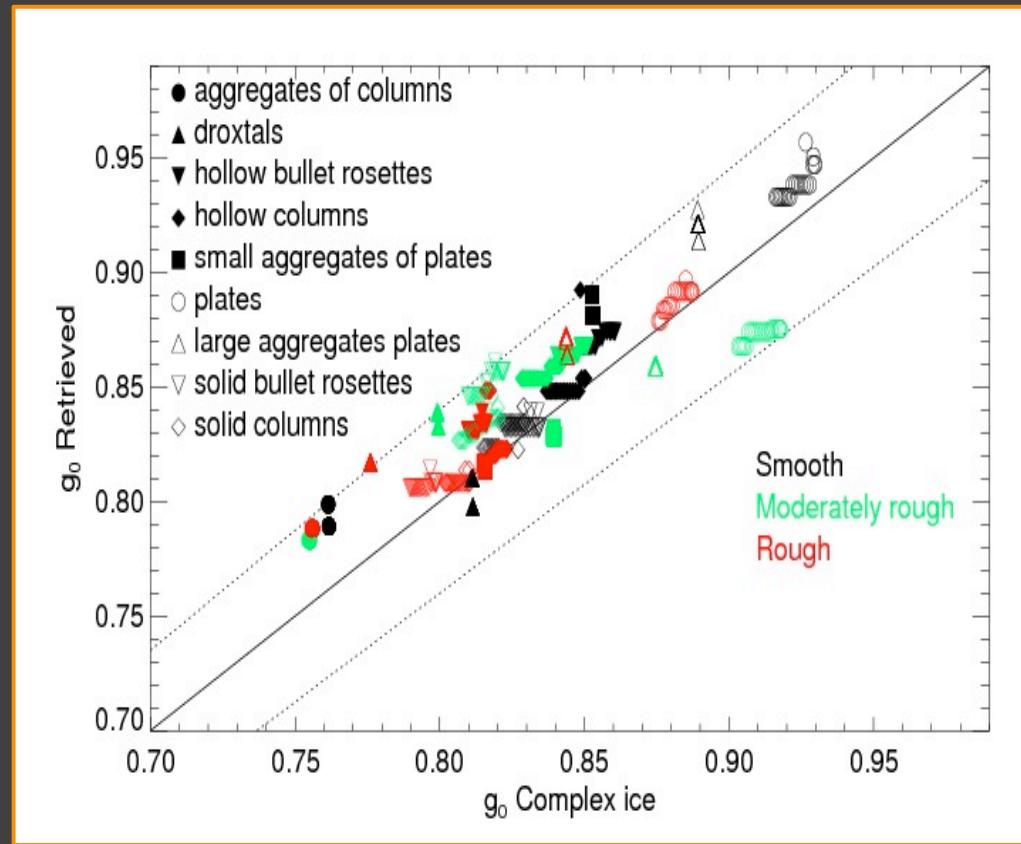
# Retrieval procedure

- LUT of polarized reflectances for hexagons
  - 50 aspect ratios 0.02 – 50
  - 14 roughness values ( $d=0$  – 0.7)
- Find best fit to measured polarized reflectances
  - 100 – 165 scattering angle
- Asymmetry parameter of best-fit hexagon is retrieved  $g$



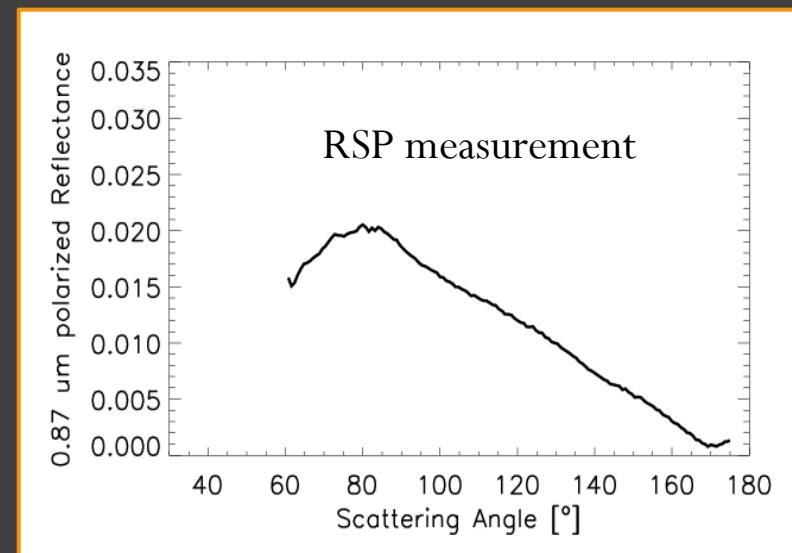
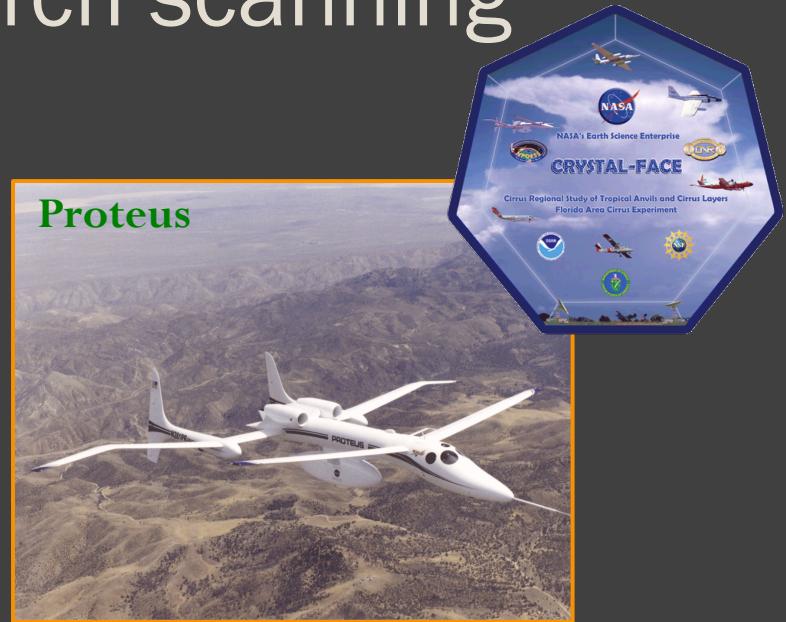
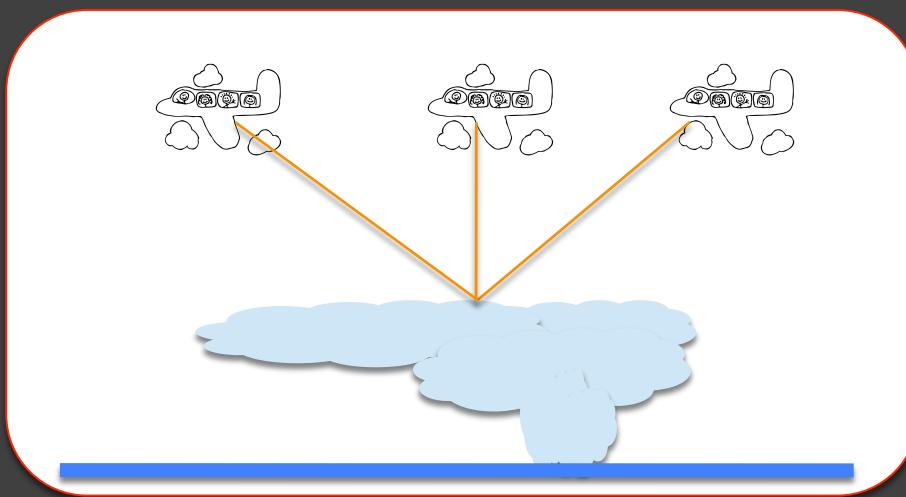
# Simulated data test

- Simulated data:
  - Doubling-Adding
  - Homogeneous cloud  $\tau = 50$
  - Complex ice optical properties (Yang et al.)
  - 50 different size distributions
  - 3 roughness degrees
- Retrieved  $g_0$  within 5%
- Mean bias: 0.014

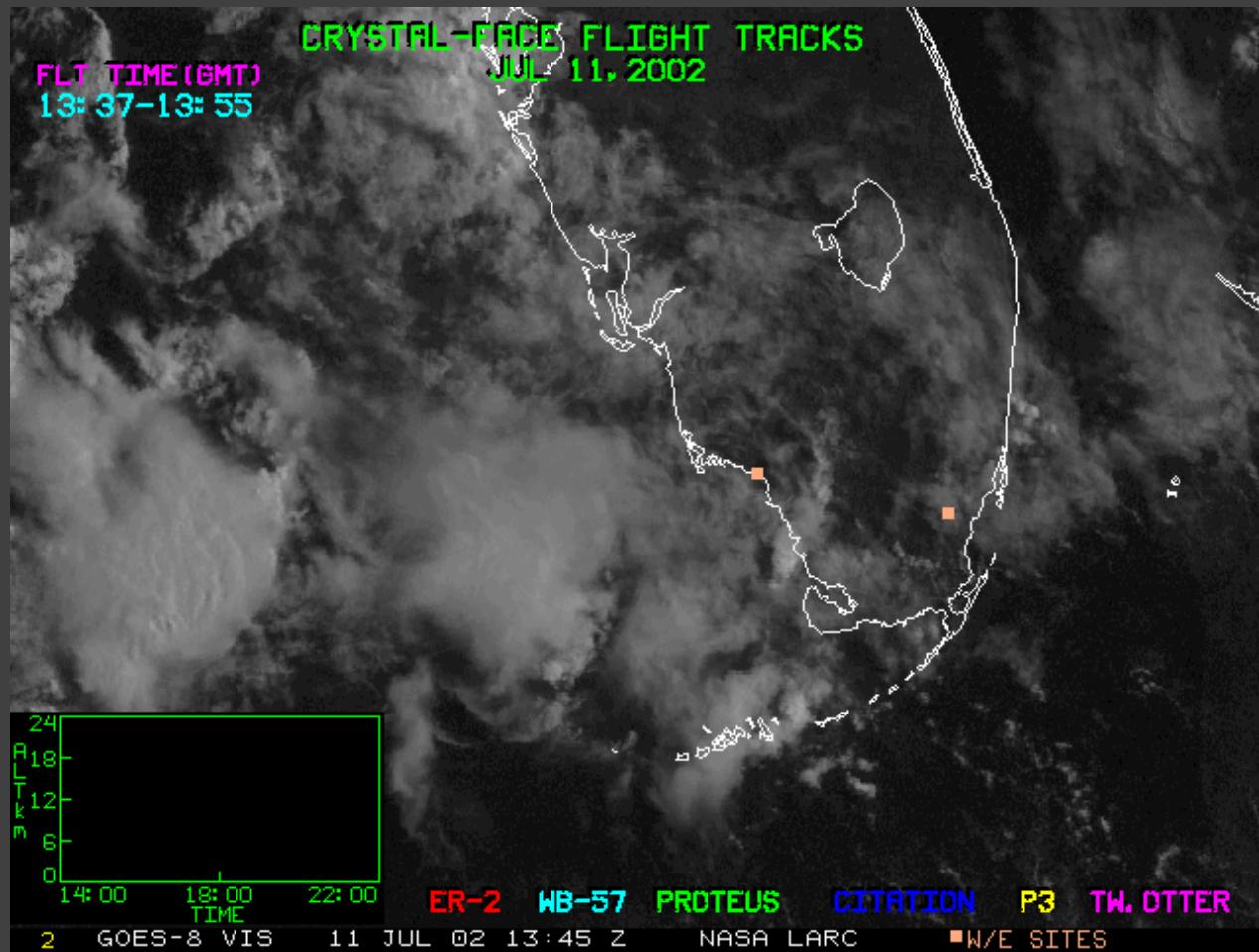


# CRYSTAL-FACE: Research scanning polarimeter (RSP)

- Airplane version of Glory-APS (launch failed March 2011)
- Total and polarized reflectances
- 152 viewing angles  $\pm 60^\circ$
- 9 bands, visible to NIR

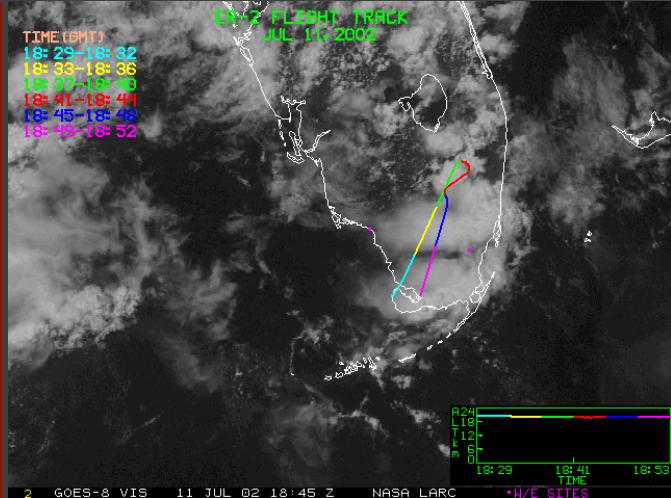
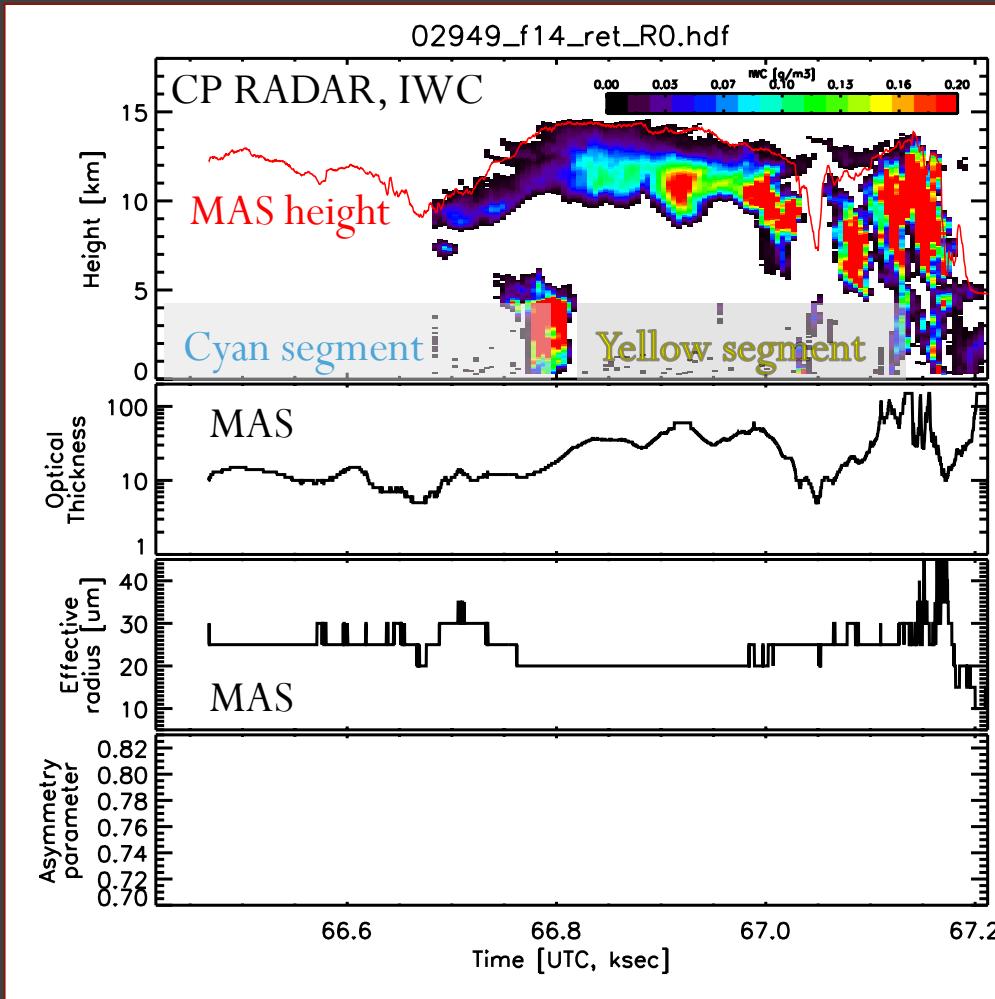


# Aircraft flight tracks: 11 July 2002



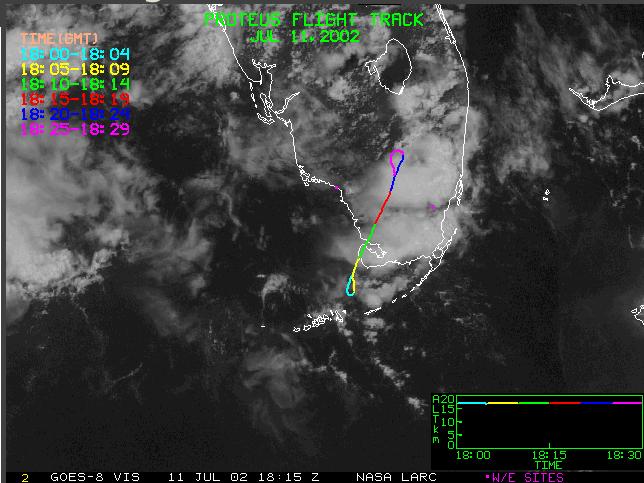
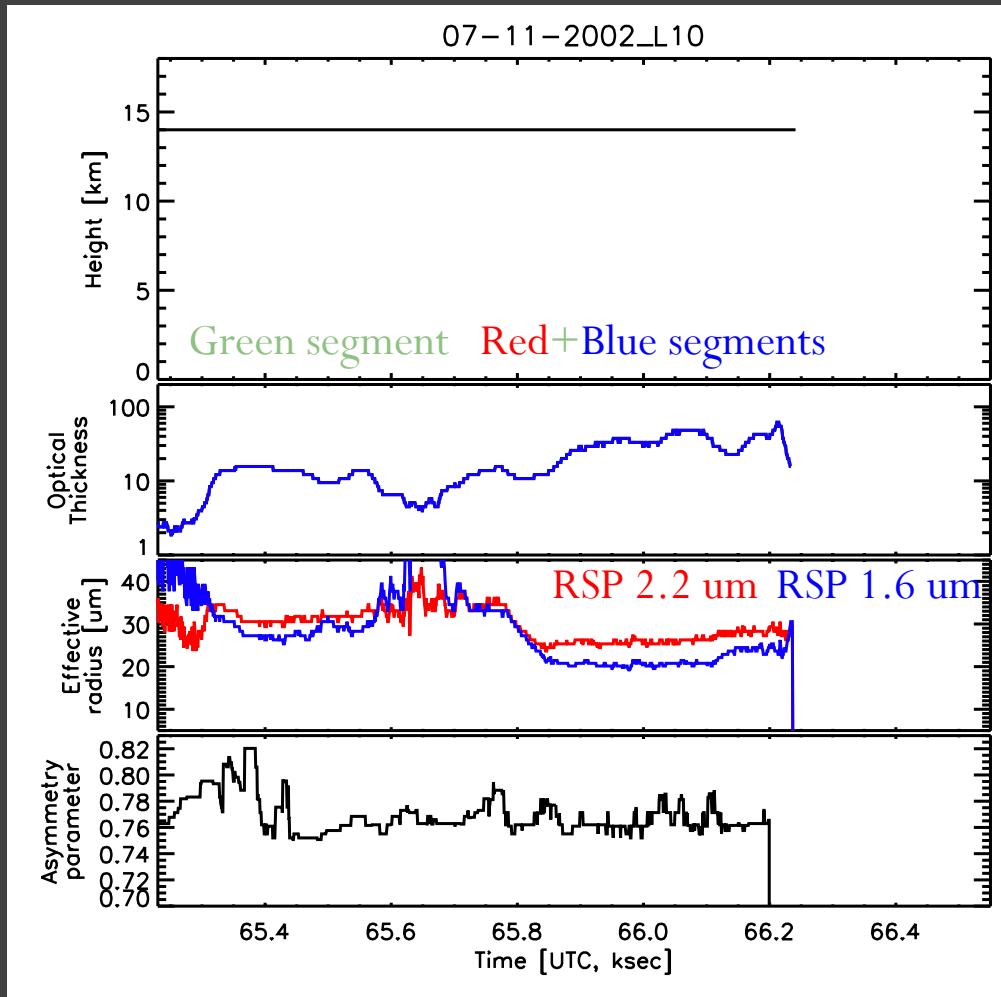
Movie at [http://www-angler.larc.nasa.gov/crystal/fltdays/all\\_071102\\_new/disp2002192.html](http://www-angler.larc.nasa.gov/crystal/fltdays/all_071102_new/disp2002192.html)

# RADAR + MAS retrievals: 11<sup>th</sup> July 2002



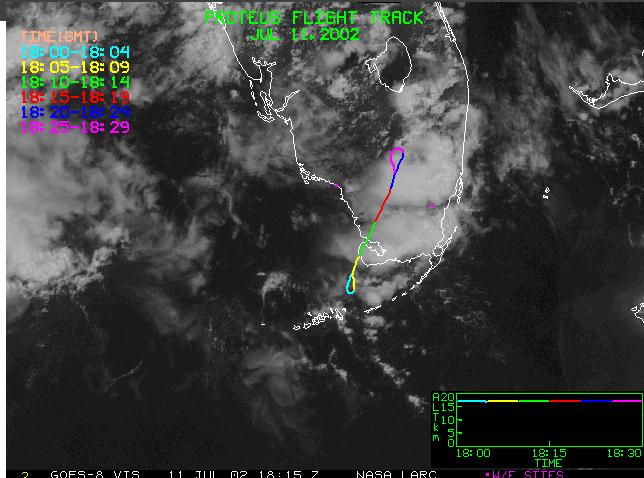
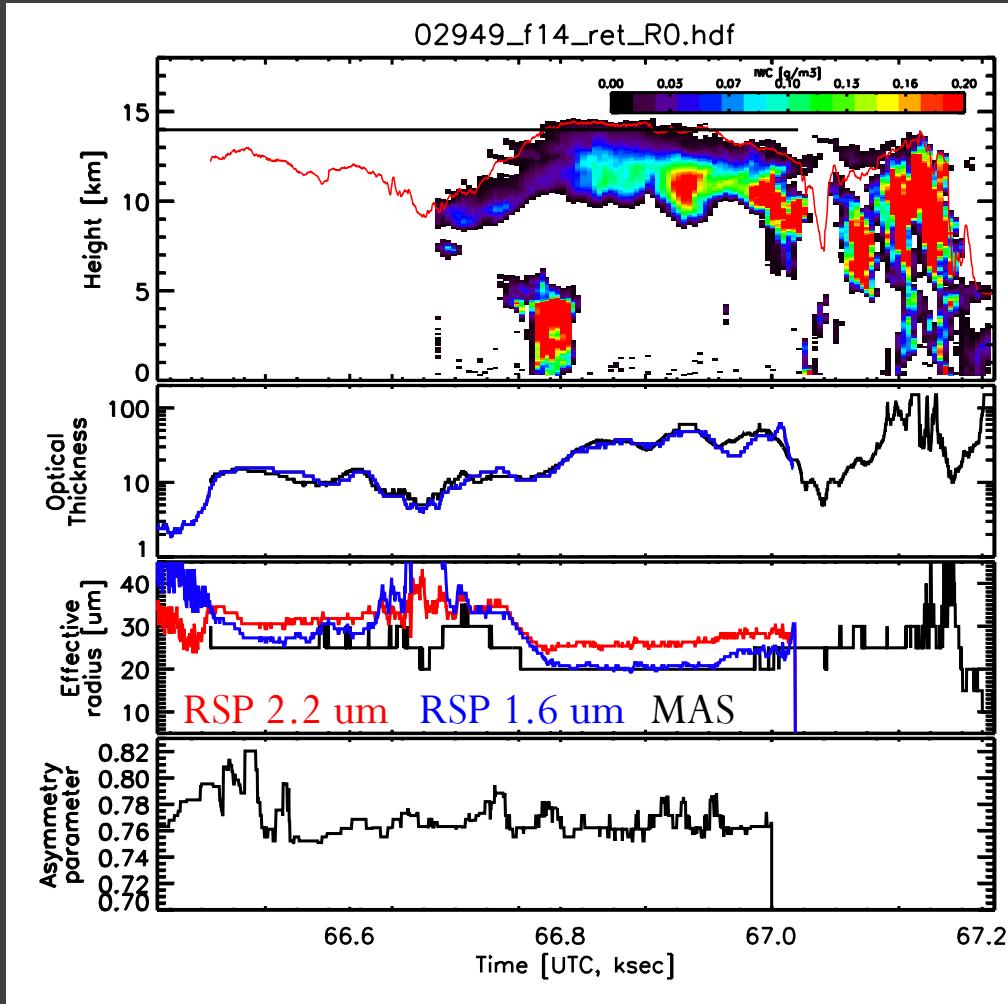
- Cloud radar (ER-2)
- MODIS airborne simulator (ER-2)
- MODIS collection 4 algorithm (old)
  - $g \sim 0.8$

# Application to RSP: 21<sup>th</sup> July 2002

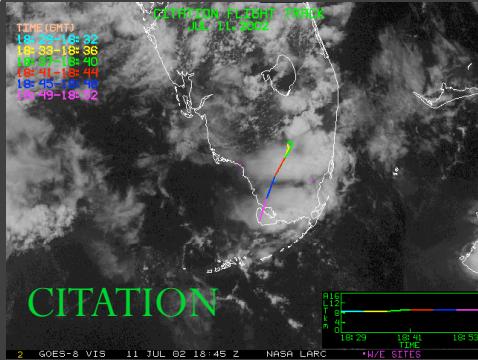


- RSP (Proteus)
- Wavelengths
  - 0.86 um:  $\tau$  & g
  - 1.6 um:  $R_{\text{eff}}$
  - 2.2 um:  $R_{\text{eff}}$  (probes deeper )

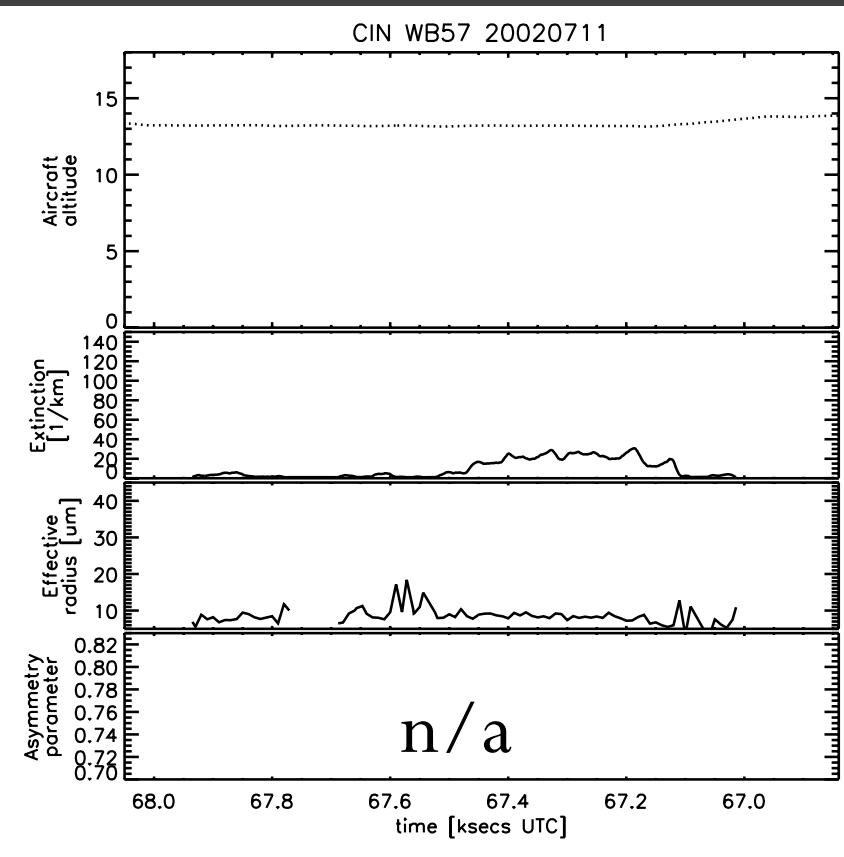
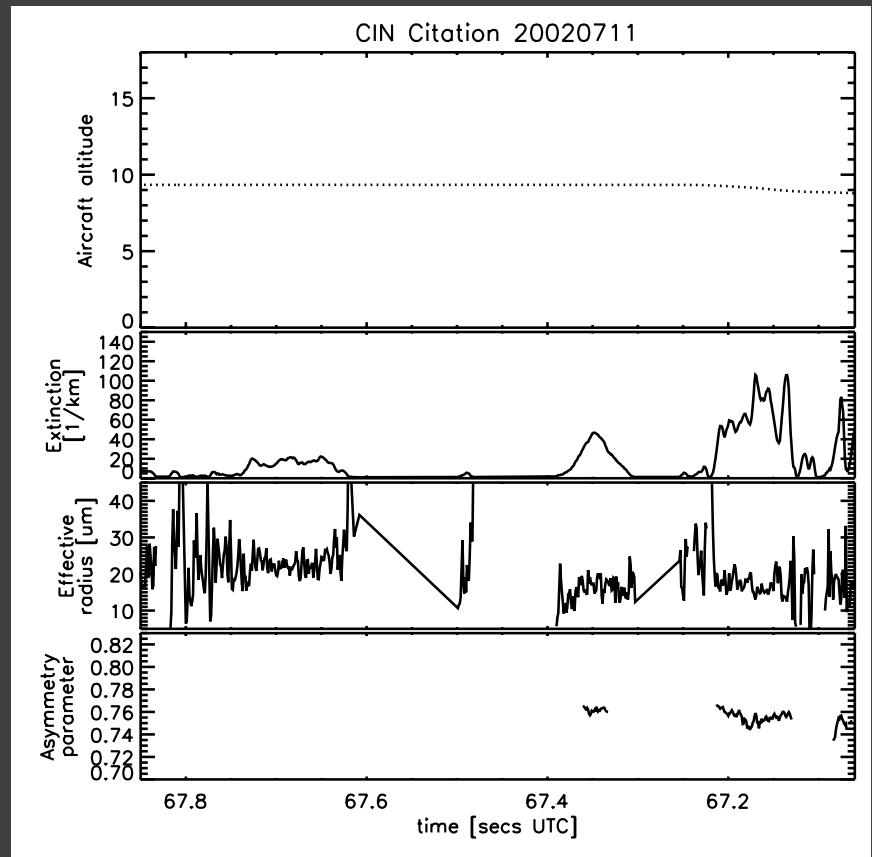
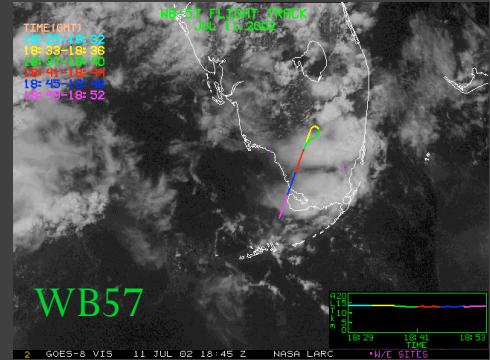
# Co-located RSP+MAS



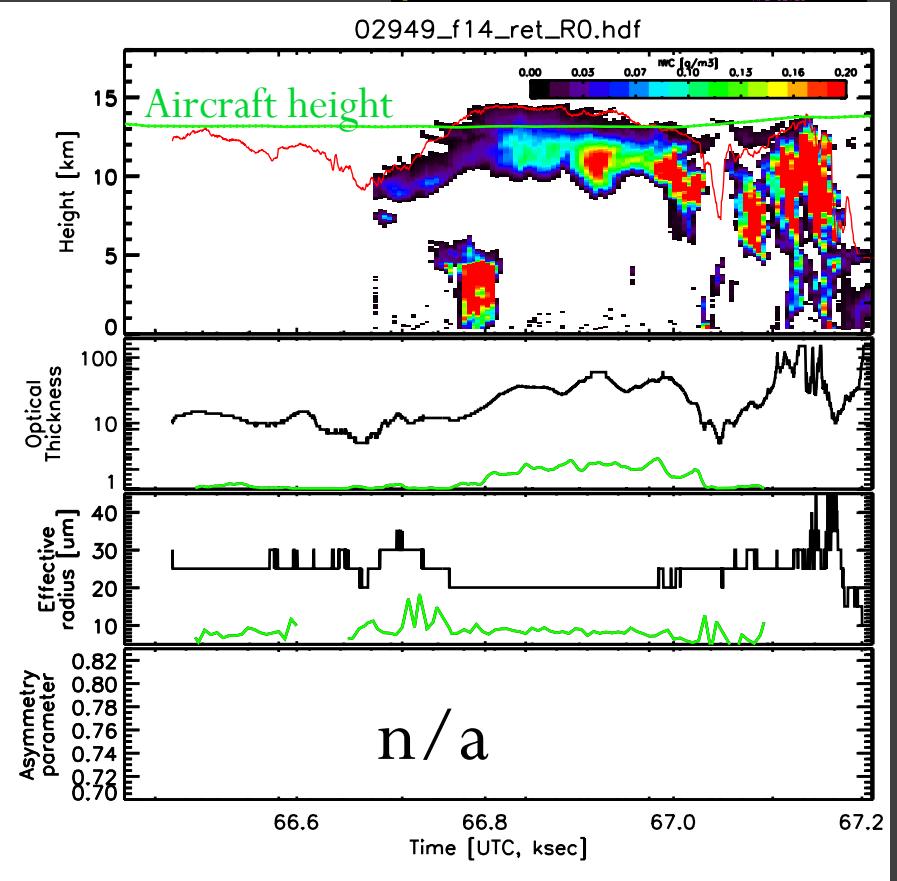
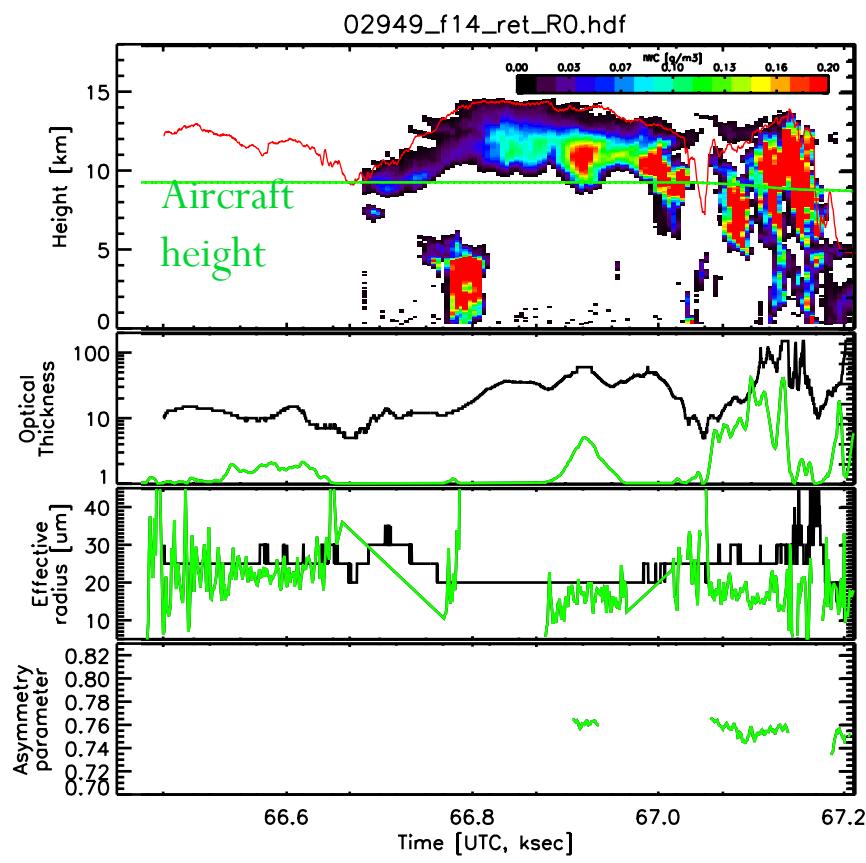
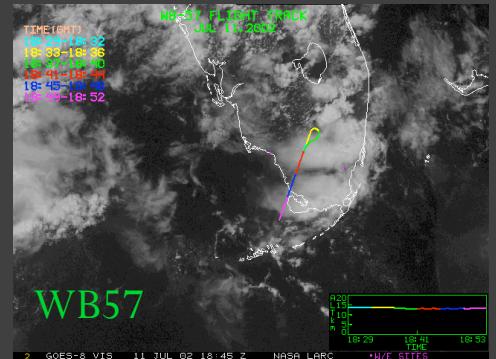
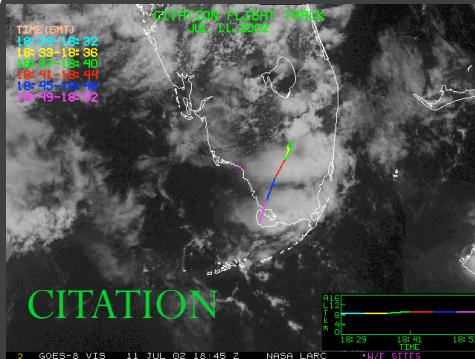
- Good comparison with MAS  $\tau$  and Reff retrievals
- Asymmetry parameter  $g \sim 0.76 - 0.78$



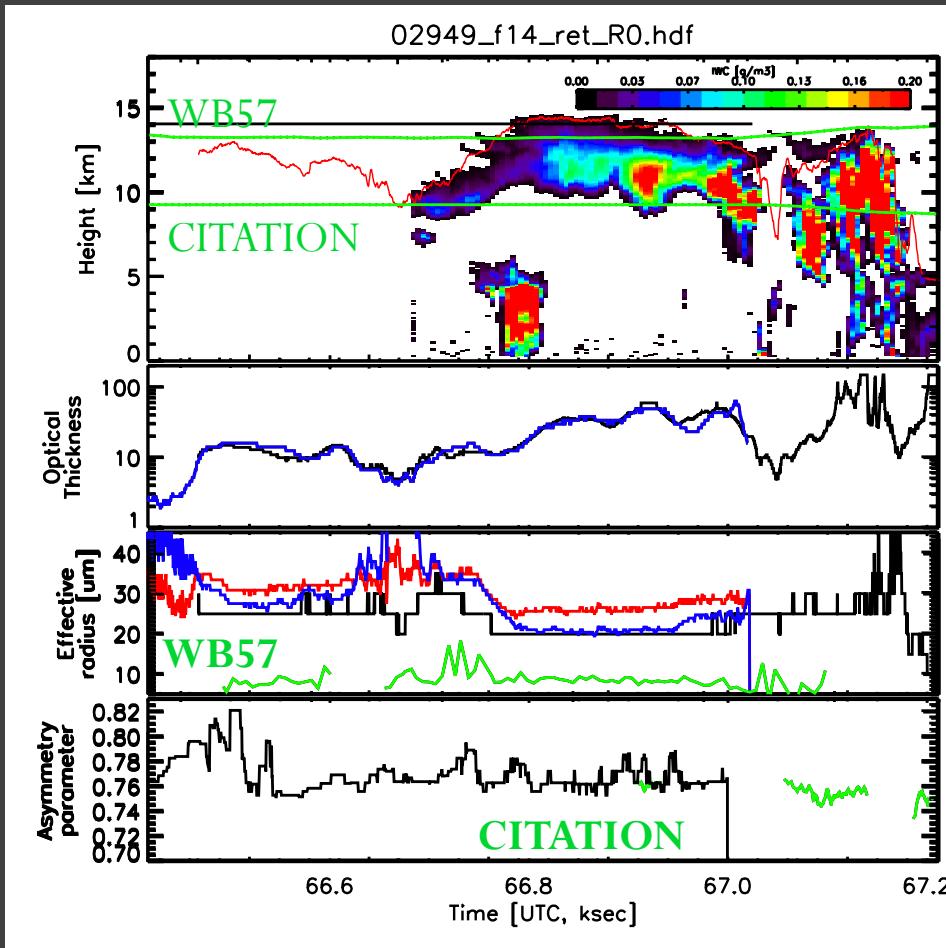
# CIN in situ measurements (Tim Garrett)



# CIN in situ measurements vs MAS

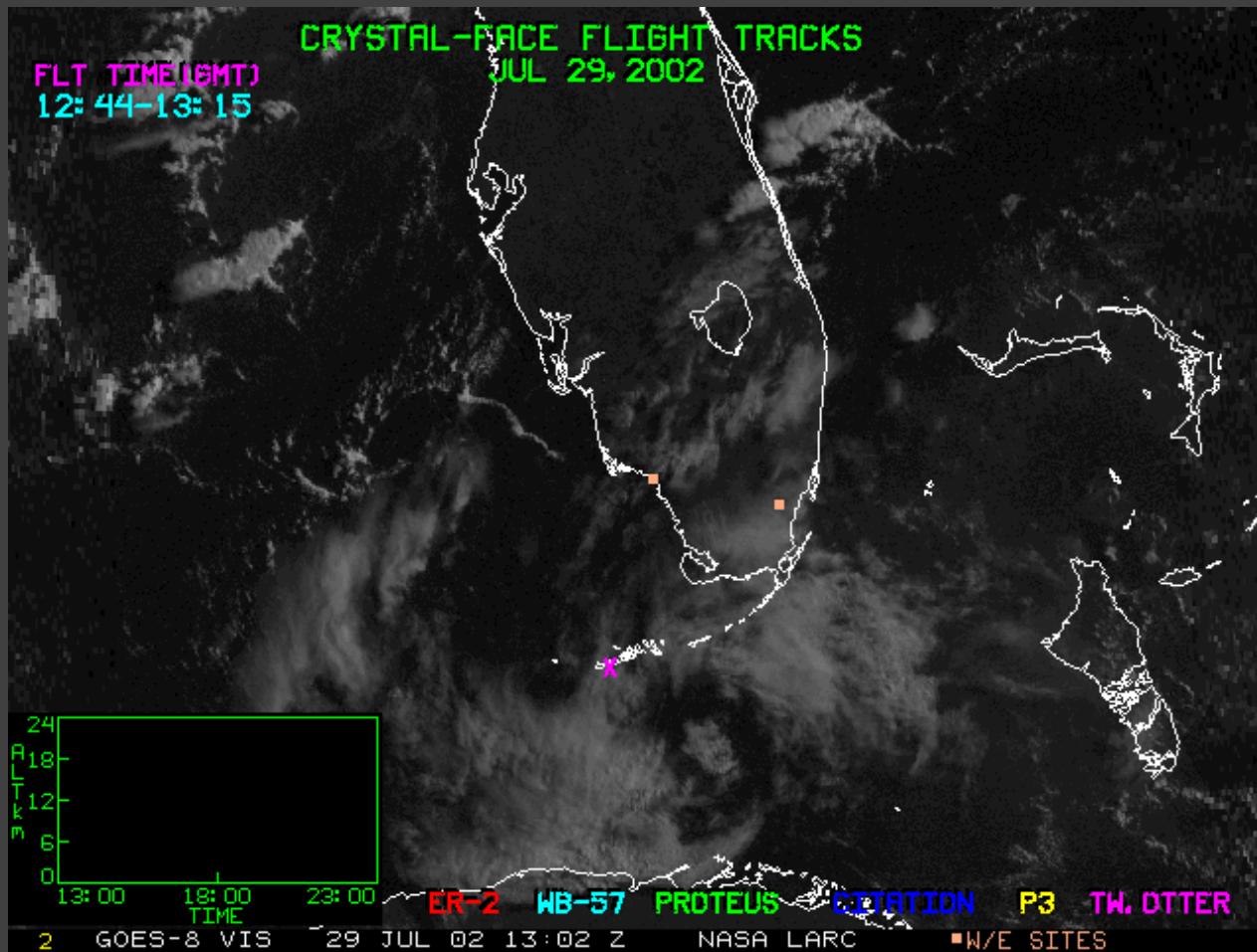


# CIN vs MAS & RSP



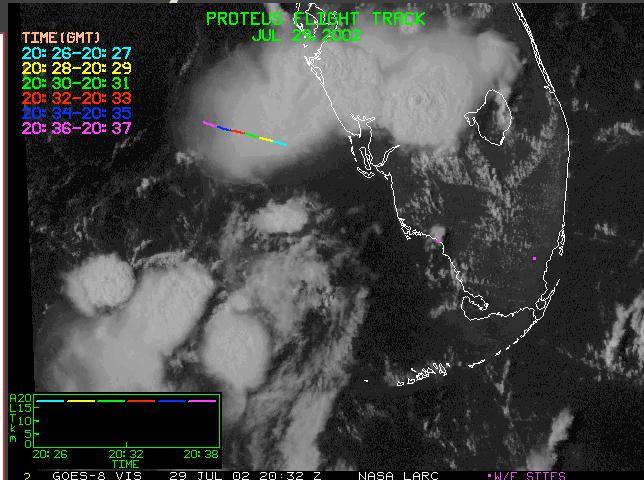
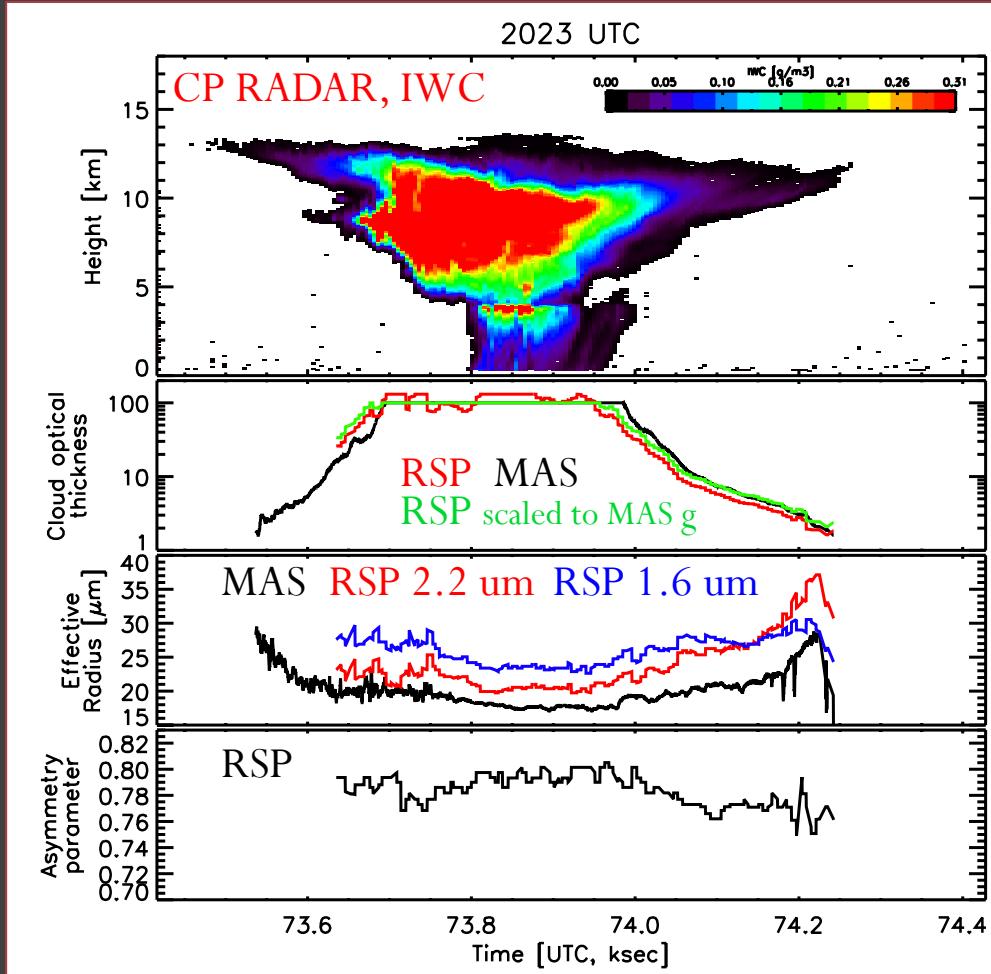
- Asymmetry parameter
  - Good comparison CIN vs RSP (but CIN at too low altitude)
- Effective radius
  - CIN factor 2-3 lower at top
    - cf. Heymsfield et al 2007

# Aircraft flight tracks: 29 July 2002



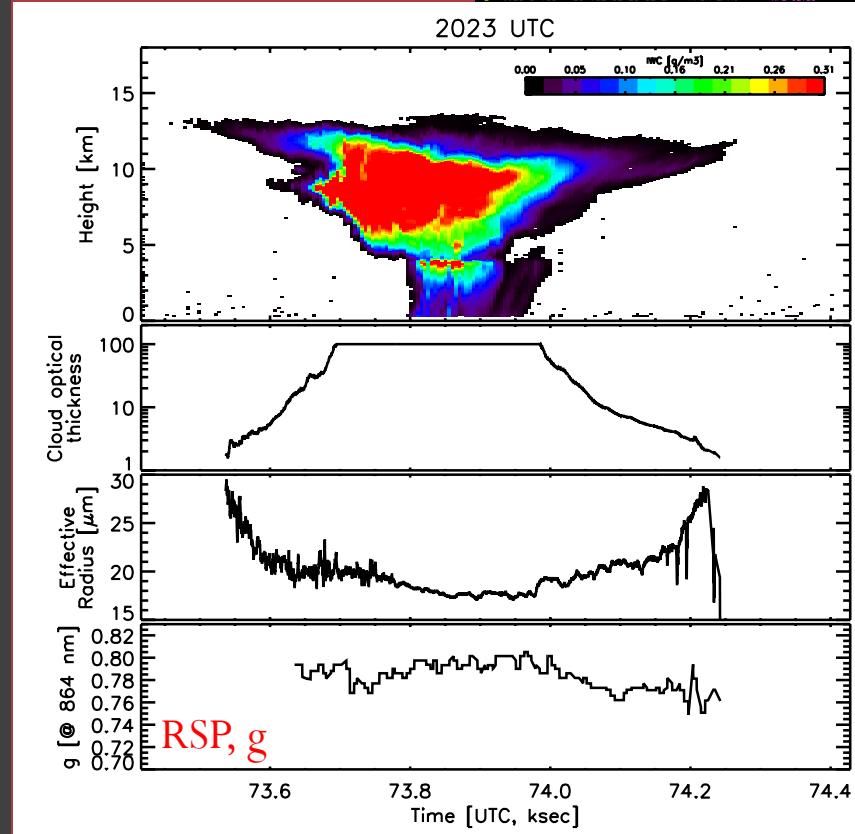
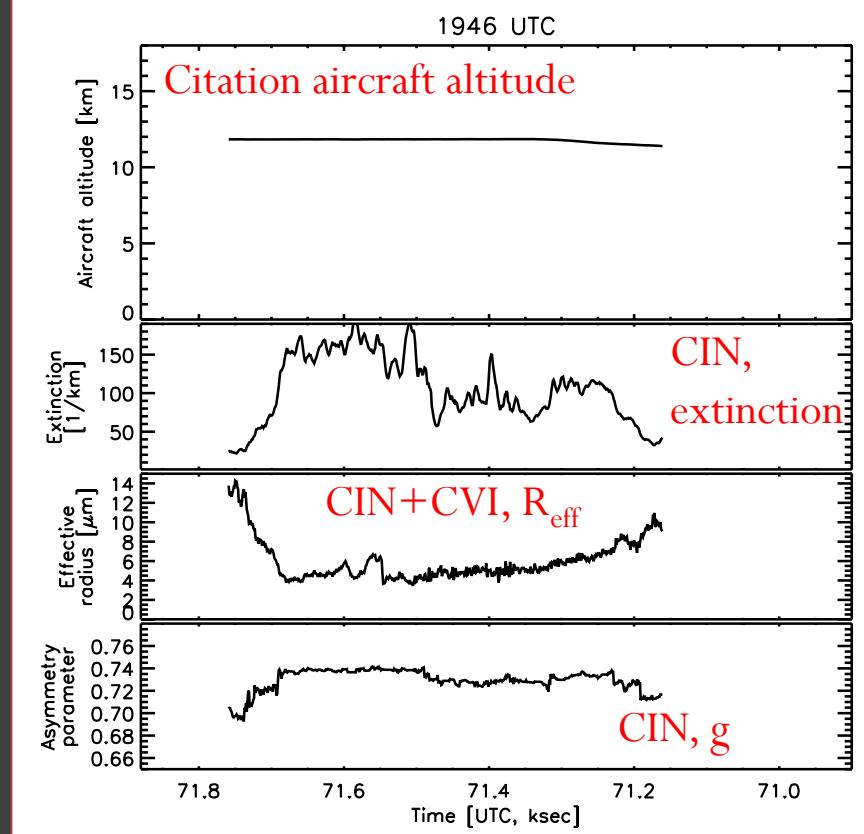
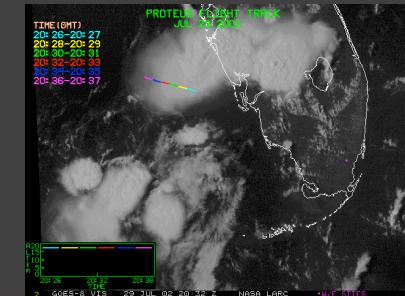
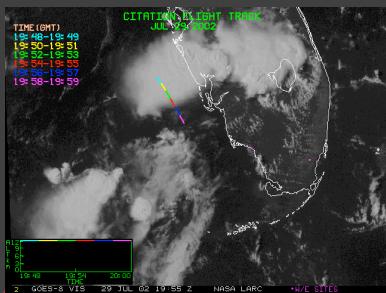
Movie at [http://www-angler.larc.nasa.gov/crystal/fltdays/all\\_072902/disp2002210.html](http://www-angler.larc.nasa.gov/crystal/fltdays/all_072902/disp2002210.html)

# Application to RSP: 29<sup>th</sup> July 2002



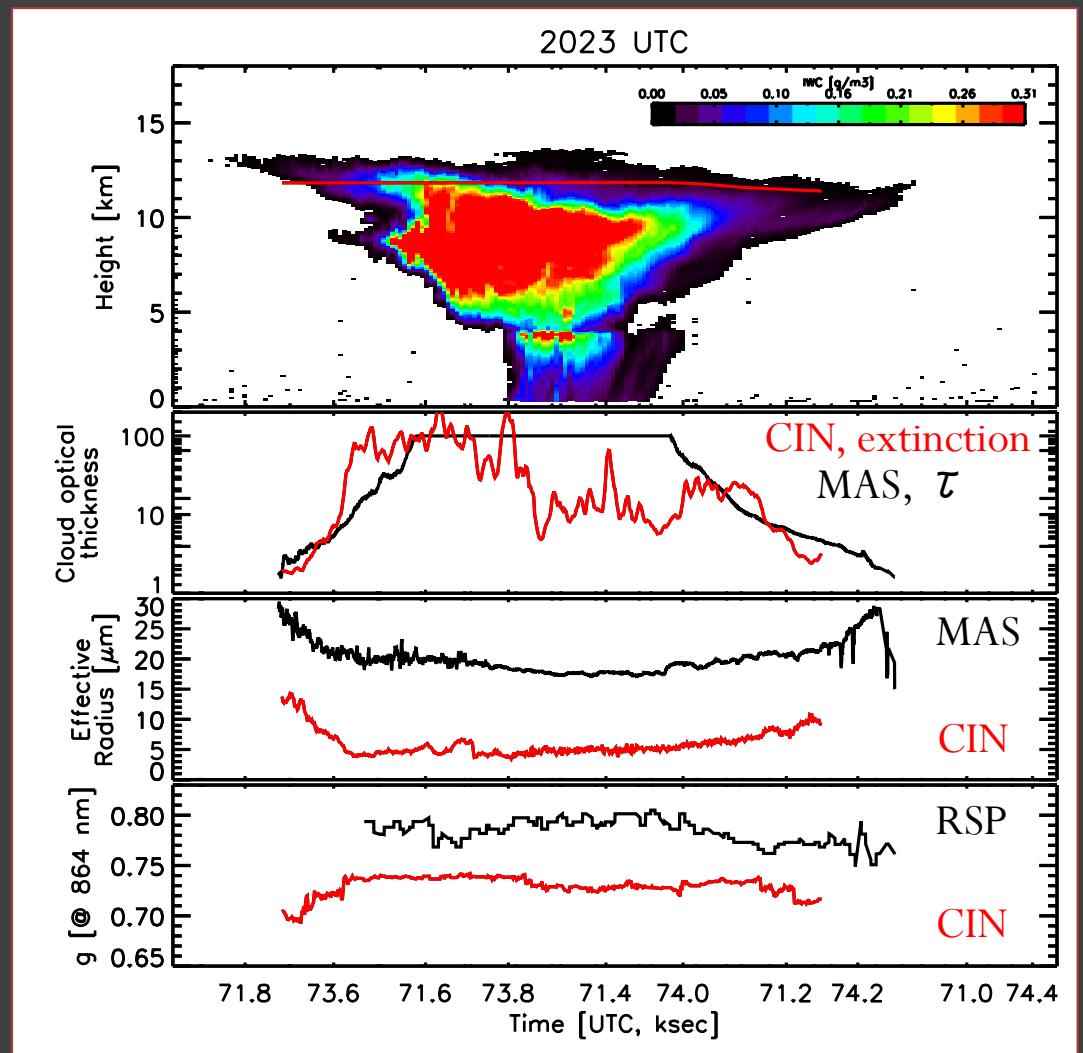
- MODIS collection 5 algorithm (new)
  - $g \sim 0.83$
- Good comparison  $\tau$
- RSP  $R_{\text{eff}} \sim 2-8 \mu\text{m}$  higher due to lower  $g \sim 0.78$
- RSP  $\lambda = 1.6 \mu\text{m}$  channel acting weird?

# Comparison with CIN in situ measurements (Tim Garrett)



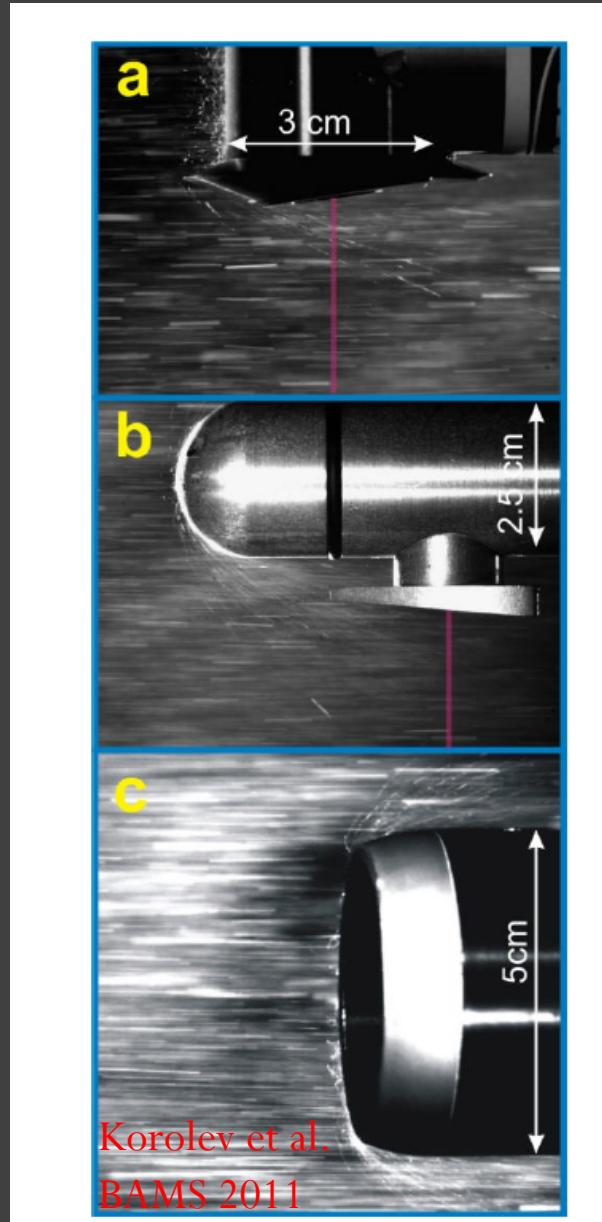
# Comparison with in situ

- $\Delta g \sim 0.04$
- $\Delta R_{\text{eff}} \sim \text{factor 3-4}$ 
  - cf. Heymsfield et al 2007
- CIN uncertainties:
  - Light leak correction
  - Calibration
  - Ice shattering on probe



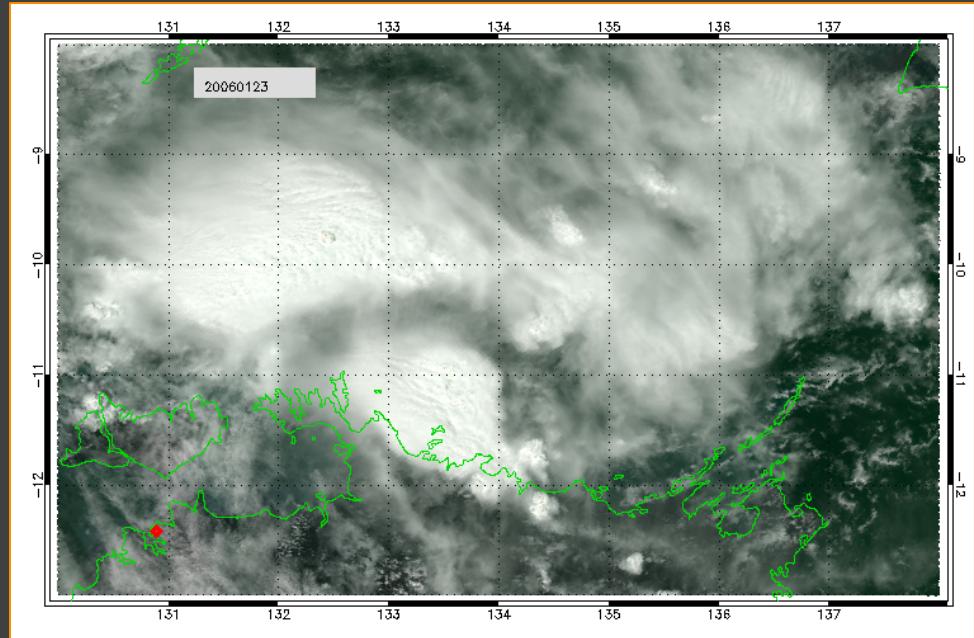
# Ice shattering

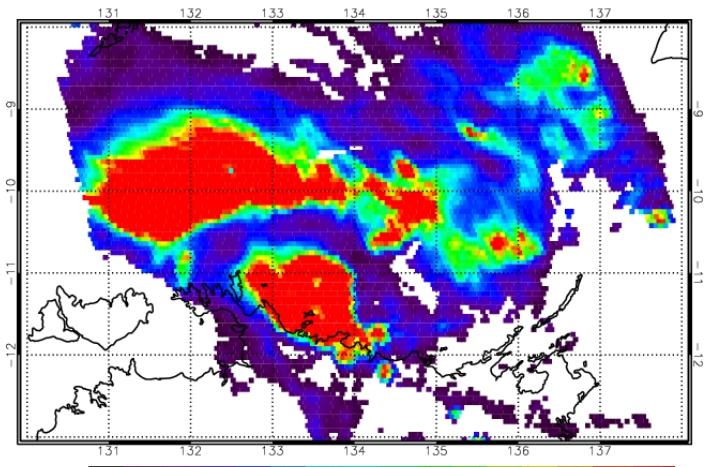
- In situ probes suffer from ice shattering on tips
- Could lead to
  - Overestimation surface and projected area ( $A_p$ )
  - Underestimation  $R_{\text{eff}} = 3/2 \sqrt{V/A_p}$
  - Error on asymmetry parameter?
- Improved probe tips developed



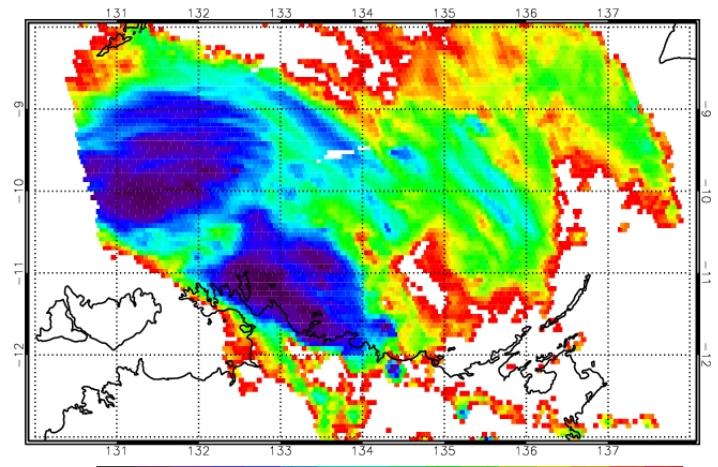
# Towards global retrievals: MODIS and POLDER (A-Train)

- During TWP-ICE campaign (Australia)
- 23 January 2006
- Very preliminary:
  - $\text{Tau} > 5$ ,  $T_b < 233\text{K}$
  - No azimuth angle dependence
  - No filtering of multi-layered clouds
  - No quality of fit checks
  - No combined  $g$ -  $\tau$  -  $R_{\text{eff}}$  retrievals

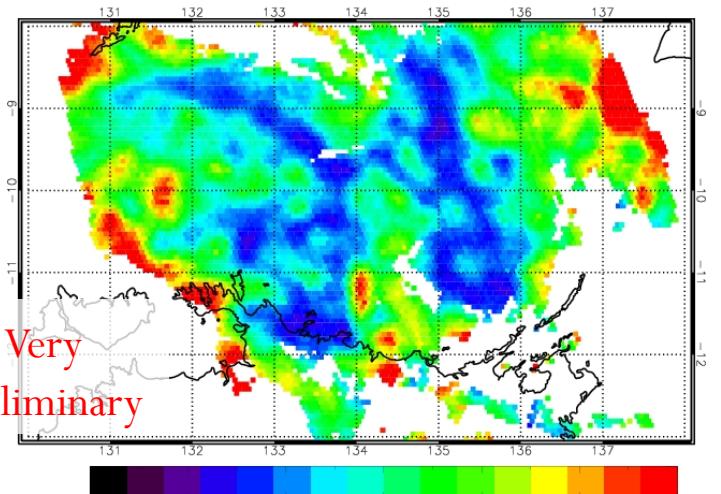




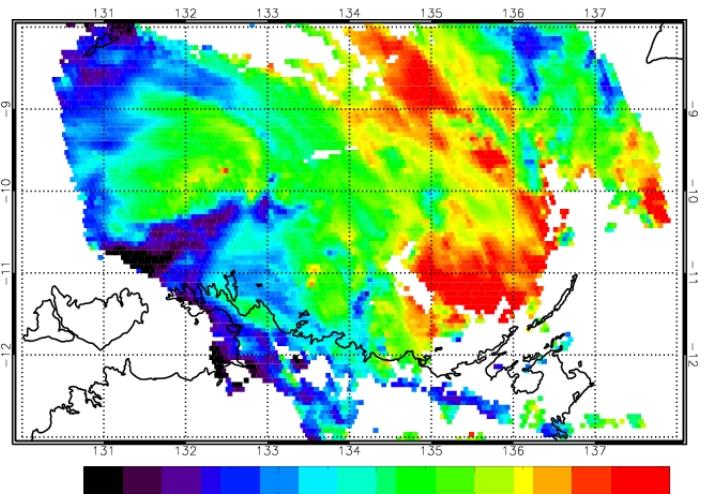
0. MODIS COT 100



180 K MODIS BT [K] 233 K



0.7 POLDER g 0.8



17  $\mu\text{m}$  MODIS  $R_{\text{eff}}$  30  $\mu\text{m}$

# Future work

- Apply to more RSP data for validation
  - CRYSTAL-FACE
  - SEAC<sup>4</sup>RS campaign (Southeast Asia, 2012)
- Investigate error sources using cloud-resolving model
  - Inhomogeneous scenes
  - 3D radiative transfer effects
  - Vertical structure (multi-layered clouds)
- Global POLDER-MODIS data
  - Filter/aggregate data
  - Validation
- Advise MODIS team on ice crystal model to use

# Conclusions

